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A CONCEPT FOR KNOWLEDGE-BASED USER SUPPORT IN NAVAL ENVIRONMENTS

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Abstract

Technology pushes for sensor and weapon systems as well as for command, control, communication, and information systems have increased the amount and complexity of information available while the time to process that information has dramatically decreased. Additionally, recent changes in military situations and doctrines have given rise to the need for computer-based aids that can support human operators in getting situation awareness and reacting to novel complex and rapidly changing situations. A concept has been developed to support the members of the decision making team in combat information centers of the German Navy vessels by knowledge-based user interfaces. Such interfaces will ease the burden of the decision makers in all phases of the military command and control cycle and enhance the effectiveness of the decision making process in novel military scenarios, e.g., in Littoral Warfare, Crisis and Low Intensity Conflicts, or Missions other than War. The paper starts with a general problem description and a framework of operator support possibilities based on a hierarchical structure of human task performance with different levels of situational complexity. It follows the description of a generic support concept by means of knowledge-based user interfaces consisting of a knowledge-based assistance system and an interactive multimedia user interface. Finally, as an example the implementation of the conceptual work into a demonstrator of operator support in naval anti-air warfare situations is presented. With this demonstrator the effectiveness of decision making and action taking support by a knowledge-based user interface could be shown.

1 Introduction

Technology pushes for sensor and weapon systems as well as for all kinds of military command and control systems (C2/C3/C4I) have increased the amount and complexity of information at hand while the time available to process that information has dramatically decreased.

Additionally, in actual military operations, e.g., in Littoral Warfare, Crisis and Low Intensity Conflicts, or Missions other than War, operators who are responsible for planning and decision making are faced with natural dynamic situations which are characterized by extremely rapid changes in the tactical situation, highly uncertain information, and a large variety of potential situational hypotheses. These decision makers undergo high mental stress due to the need to respond quickly and accurately, or face potentially fatal consequences.

It may currently not be possible to design a system which can cope with all conceivable events in highly ambiguous situations, for instance, with those found in novel military operations. But it is already possible to develop a system that complements human's abilities in perceiving and assessing such situations as well as responding appropriate in unknown situations.

Operator support by intelligent and adaptive knowledge-based user interfaces is considered to be a viable approach to overcome some of those difficulties decision-makers are faced with when having to cope with complex command and control systems in novel military situations. Such user interfaces consist of a knowledge-based assistance system and an interactive graphical or multimedia user interface. They can support military decision makers in performing information gathering, information processing, and information entering in all phases of a command and control (C2) cycle, i.e., in situation perception (observe), situation assessment (orient), decision making (decide), and action taking (act).

2 Human Task Performance and Operator Support in Complex Situations

Situational awareness (SA), that is a reliable assessment of the situation in which a ship operates, is vital for the successful completion of its mission. To establish and maintain SA, information from own sensors or other sources of significant data and conditions must be processed. This information concerns the tactical environment as well as the own combat (sub)system(s).

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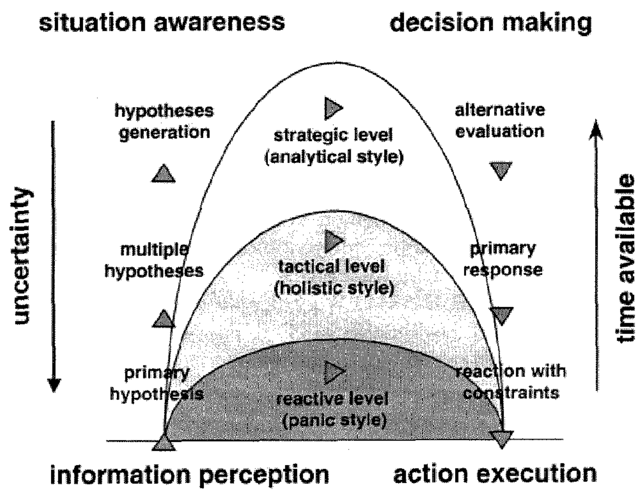

Figure 1: Situation awareness and decision making with uncertainty and time pressure

In order to provide a reliable information basis for carrying out missions, it will be necessary to assess and reassess the situation on a continuous basis. Normally, little is known about the operational environment with certainty. Therefore, to establish SA hypotheses about the behavior of both identified and unidentified objects as well as about the overall tactical and strategic situation have to be generated. Uncertainty and imprecision in observation and information gathering will quickly result in very large numbers of hypotheses that will have to be managed by human decision makers. This demand cannot adequately be satisfied under constraints of information overload and time pressure (Fig. 1).

When being confronted with complex situations three levels (styles) of decision making can be defined as reference points on a "cognitive continuum" [Amat, 1995]:

- reactive level (panic style) -
  in the case that SA may be incomplete or even very reduced because of time pressure and information uncertainty the decision making style will correspond to a panic behavior that leads to impulsive selection of a course of action based on a primary situation hypothesis.
- tactical level (holistic style) -
  familiarization and the expertise acquired play a crucial role in operator decision making. When the operator recognizes a situation as belonging to his catalogue of experienced situations, he associates to this picture a course of action. The first hypothesis that works is adopted and implemented. This holistic style of decision usually provides good results. Under high time pressure or mental workload most of the time holistic strategies will also be used with good but sometimes with less desirable results.
- strategic level (analytical style) -
  the analytical style corresponds to a "theoretical" strategy. It is the most time consuming and mentally demanding style. On this level an operator makes a detailed assessment of a situation, gathers the maximum of data, defines the problem, forms a list of alternate solutions to the problem, chooses selection criteria, ranks them by priority and selects the alternative having the greatest weight within the space defined by the selection criteria. The aim of this strategy is to find the optimum solution.

The task of gathering and correctly combining different types of data, information, reports, and messages and then drawing accurate conclusions still remains the responsibility of the military decision makers who are usually under great strain during tactical operations. Generic cognitive tasks to be performed by means of C2 systems are information gathering/situation perception, situation assessment, goal establishment, decision making/action planning, action command, and control of action accomplishment for goal achievement. These cognitive tasks describe the course of activities in military C2 cycles and in nonmilitary decision situations, too. Differences in situational familiarity, information uncertainty and time pressure are related to different cognitive processes corresponding with differences in control effort and time consumption. Effort and time increase from simple decisions with quick reactions for routine tasks in clear situations to task of higher complexity with cognitive demanding tasks in ambiguous situations.

For developing support systems that assist the operator in complex decision situations it is useful to obtain and apply a model of the human decision making and problem solving process. This model has not to be an exact reproduction of human cognitive processes. Rather, it should enable identifying possibilities for situation-, task-, and user-based assistance of the decision making and problem solving process. Such assistance should comprise information presentation for situation assessment, information processing for solution

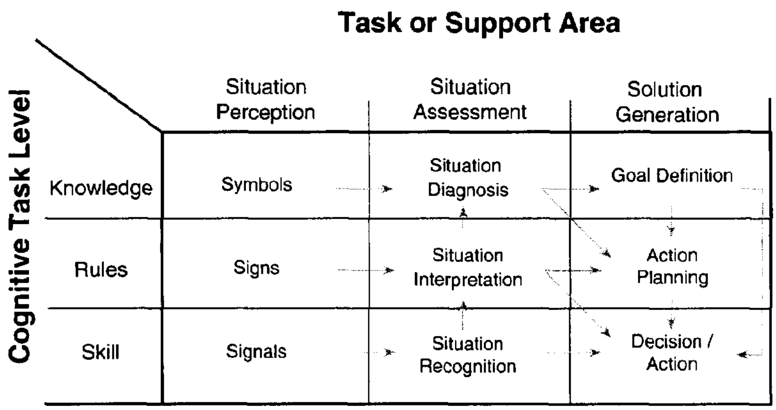

Figure 2: Concept structure of human problem-solving activities

preparation, and operator guidance for information entering to execute tasks.

To establish such a general model, complex operator tasks are divided into three different performance phases according to the normal approach of operator problem solving behavior: (1) situation perception, (2) situation/problem assessment, and (3) solution generation. Additionally to structuring problem solving tasks horizontally into phases, a vertical structure seems to be appropriate for each of the three performance phases. This vertical structure is related to the specific types of situations with different cognitive complexity one has to cope with in natural settings. For this structure the conceptual model of Rasmussen [1983] for skill-, rule-, and knowledge-based operator behavior in performing complex tasks can be adapted as a framework. The resulting concept takes into account the different situations which arise, for instance, in novel military scenarios, i.e., routine, familiar, and unfamiliar situations. The hierarchical differentiation dependent on situational familiarity, expertise, and cognitive operator demand corresponds also to the steps of mental activity which Lim et al. [1996] applied for describing human-computer interactions. This model contains the following steps: perception, interpretation, evaluation, goals and intention, action specification, and execution. Combining the hierarchical differentiation of the three performance phases of problem-solving tasks with the cognitive steps of the model of Lim et al. a conceptual framework has been developed that describes the problem space of human decision-making and problem-solving in complex naturalistic situations with a 3 x 3 matrix (Fig. 2).

On the lowest level of this framework skill-based behavior corresponds to nearly unconsciously and automatic information processing in routine situations or under time pressure and to executing tasks at an reactive level (Fig. 1). On the second level rule-based behavior corresponds to stereotyped information processing in well-known situations at an tactical level or holistic style. On the upper level knowledge-based behavior corresponds to a conscious, controlled, and analytical problem solving using situation analysis and evaluation as well as planning and decision making activities.

Applying the hierarchical structure of human problem solving activities to a realistic problem situation, the following steps of information processing, i.e., situation perception, situation assessment, and solution generation can be identified:

- information, i.e., states from environmental objects, the technical system or the operator behavior is perceived and monitored by a situation assessment process. Relevant status changes, i.e., events are detected and the related information processed. The result leads directly to a reflexive action by the decision/action step of the solution generation process if the information belongs to a well known and recognized routine situation.
- if the available information does not directly lead to a reflexive situation/reaction routine the situation assessment process has to interpret the available information using known heuristics, i.e., using already existing hypotheses about the familiar situation, to come to a situation interpretation. The result of this interpretation will be used by the action planning step of the solution generation process to decide about the appropriate reaction or to plan the appropriate course of actions, if necessary.
- if the information is ambiguous or uncertain and the situation is unfamiliar or ill structured so that the situation assessment process is unable to directly recognize or interpret the situation by known rules, a situation diagnosis has to be performed. On the basis of the diagnosis a course of actions will be identified by the action planning step of the solution generation process if the result of the diagnosis corresponds to the predefined goal. Otherwise, a new goal and the corresponding action sequence for achieving it has to be determined by the solution generation process. This decision depends on the complexity of the hypothesis determined by the situation assessment process.

3 Concept for a knowledge-based operator support

To support the human operator in SA and decision making with complex systems in naturalistic situations adaptive aiding concepts have been developed [Rouse et al., 1988; Rouse, 1991]. These concepts have been developed to overcome human deficiencies in information perception and processing. They have actually been applied as aids for aircraft pilots as a so-called "pilot's associate" [Rouse et al., 1990; Amalberti et al., 1992; Wittig, et al., 1992)]. The basic idea of these concepts is that an overall automation must not be the objective of system development [Bainbridge, 1987]. The human operator should be involved in the decision making process as far as his abilities and his performance are sufficient for achieving mission goals. An aid is provided only to enhance human abilities (e.g. in detecting and evaluating complex patterns or reacting on unforeseen events) and to overcome human deficiencies (e.g. when doing mathematical calculations), i.e., to complement individual human performances.

3.1 Concept of a Knowledge-Based Assistant

For the reasons mentioned, the concept of human-centered automation recommends a computerized assistant that complements the operator like a human partner. The human user is engaged in a cooperative process in which human and computer assistant both initiate communication, monitor events and perform tasks. The computer assistant does not act as an interface or layer between the user and the command system. In fact, the most successful assistant systems are those that do not prohibit the user from taking actions and fulfilling tasks personally, i.e., behaving as a personal assistant that cooperates with the user on the same task. Thus, in parallel to the human operator, the assistant monitors the situation (e.g. states of the system and the environment) and, additionally, operator actions. If the assistant discovers critical situations or inappropriate operator behavior, it may automatically perform some operator-related functions. Faulty behavior of the operator will be classified, announced, and if there is no reaction from the operator, possibly compensated by the assistant. But in any case the user is able to bypass the assistant, so that the responsibility and ultimate decision remains with the human operator.

The knowledge-based user interface [Berheide et al., 1995] to support human operators consists of a knowledge-based user assistant (KBUA) and an interactive multimedia user interface (Fig. 3). Information presentation and the user dialog with the C3 system are accomplished via the user interface which acts as the communication tool for the user with assistant and C3 system.

The knowledge-based user assistant is not an automation or expert system in the conventional sense but contains the knowledge of domain experts and makes it available on the user interface to assist the human operator, e.g., according to situation, mission, task, system states, or operator needs. This aiding or assistance will be attained by a situation- and task-related information presentation and information processing, as well as by means of operator action guidance according to situation relevant tasks and course of actions combined with information input.

3.2 Functional Structure of the Knowledge-Based User Assistant

The functional structure of the KBUA itself consists of three components, i.e., a situation monitor, a solution generator, and an information manager (Fig. 4), representing the three different areas of the general task performance or support structure: (2) situation/problem assessment, (3) solution generation, and (1) situation

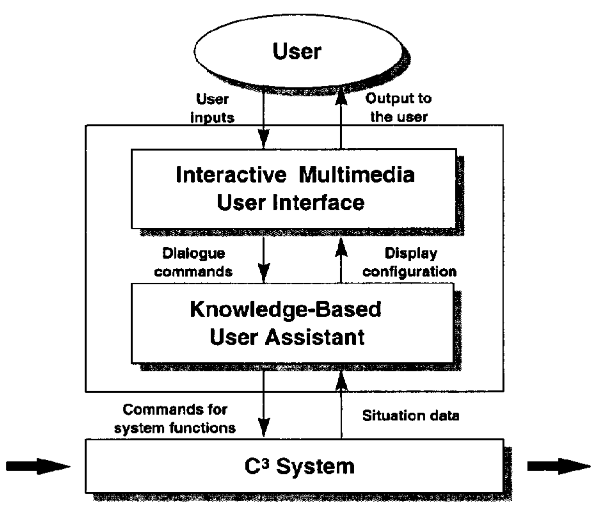

Figure 3: Concept of a knowledge-based user interface

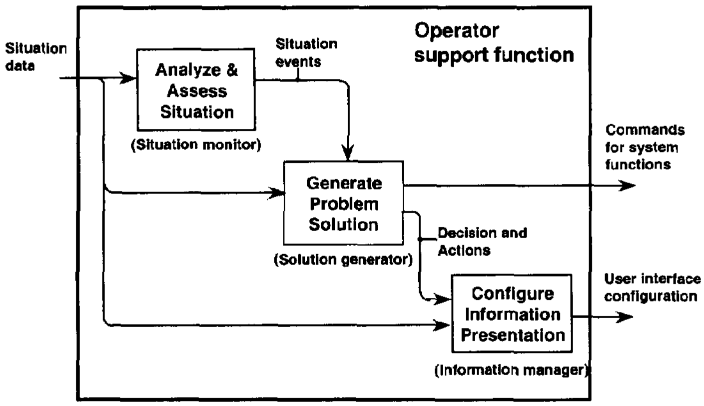

Figure 4: Functional structure of the knowledge-based user assistant

perception/information presentation [Dörfel et al., 1997].

The *situation monitor* supports the operator in gathering information and assessing situations by means of reviewing and analyzing situational data with regard to relevant situational events. The situation monitor itself consist of three different parts monitoring the external situation, the overall system status, and the operator behavior by means of predefined filter functions. The present implementation of this monitor contains only filter functions to monitor the external situation. Later on it will contain functions to monitor system status and operator actions, too.

Problem- and task-relevant situation assessment by the situation monitor is the basis for the *solution generator* to define goals, plan actions to reach newly defined goals or predefined objectives, and generate appropriate decision proposals. Dependent on situation assessment and the time available the planning part of the solution generator decides about function allocation between human operator and machine system components, i.e., "which function" to be accomplished "by whom" and "when", as well as about the information and action requirements of the human operator, i.e., "what" information or action possibility to provide and "when".

Necessary information as well as required action possibilities are presented on the user interface by means of the *information manager*, supporting the information perception process of the human operator by deciding "how" the presentation should be designed and performed.

This general concept of the knowledge-based assistant can be applied to different problem areas as well as to different kinds of operator support. However, specific problem areas require establishing domain-specific contents for data and knowledge bases as well as availability of problem-specific reasoning and problem solving processes, like rule-based or case-based reasoning, diagnosis, and handling of uncertainty by probabilistic reasoning or belief networks. Using the proposed 3 x 3 matrix of problem solving performance (Fig. 2), as an orientation already existing solution systems for restrictively supporting reactive, planning, or decision making tasks can be identified and integrated advantageously into a new support concept. In this way, the matrix structure with its elements allows a modular development and a stepwise implementation of a knowledge-based support concept. This enables developers to quickly react on situational demands.

4 Application of the Proposed Concepts

To demonstrate the applicability of the described KBUA concept for efficiently supporting military decision makers in complex situations demonstrator systems have been prototypically developed for exemplary tasks. In the following one application will be presented in some detail.

In a research project for the German Navy the concept of a knowledge-based user interface has been applied to develop an aid for the Identification/Recognition (ID/REC) process in ship air defense [Dörfel et al., 1999]. The special support concept consists of a number of support functions for an event-related information and task management to efficiently perform the identification process.

The development started with the specification of a realistic crisis reaction scenario. On the basis of this scenario the following operator tasks have been identified for support: a) monitoring the established air picture to detect specific task relevant events, b) identifying newly detected tracks, c) changing the identity of already identified tracks if necessary, and d) performing the investigate procedure for SUSPECT or HOSTILE tracks showing threat relevant behavior.

In cooperation with naval experts a limited number of exemplary criteria have been defined from the scenario and assigned to ID states of a track. From these criteria an event list has been deduced to define ID state transitions caused by situational events. Fig. 5 shows the corresponding state transition diagram of a track comprising ID states, exemplary situational events, and

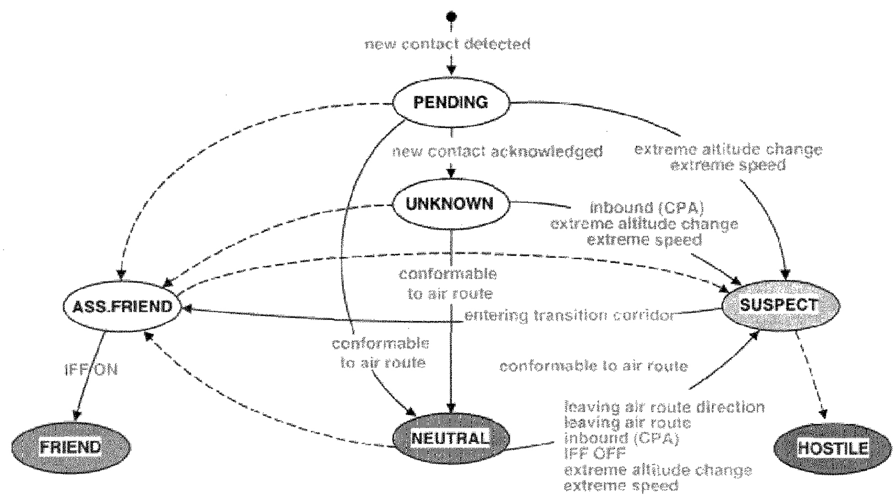

Figure 5: ID state transition diagram for exemplary events

related state transitions. This diagram has been used for developing the logic of the situation monitor, the functions of the solution generator, and the user interface configurations applied by the information manager.

The ID/REC process has been supported by presenting actual data as well as preprocessed situational and task relevant information on an interactive graphical user interface. Additionally, the operator has been guided by providing information entering possibilities on this interface (Fig. 6).

Each task-relevant situational event will be notified at the user interface by presenting a virtual event/action button (VEAB) and a related information/action window. The VEABs are prompts or warnings about the occurrence of task-relevant events or calls on performance of special tasks for related tracks, respectively. Additionally, they present important information about those tracks. The VEABs are arranged by priority where VEABs for critical events or tasks with a high performance priority are placed most left. After confirming a notified event or accomplishing a task called for the related VEAB will be deleted.

Activating a VEAB will open the related information/action window (IAW) for the specific track. Track number and specific icon as well as type and class of the track are presented. Situation perception as well as situation assessment are supported by the presentation of actual track attribute values and preprocessed information like trend information, min/max values of

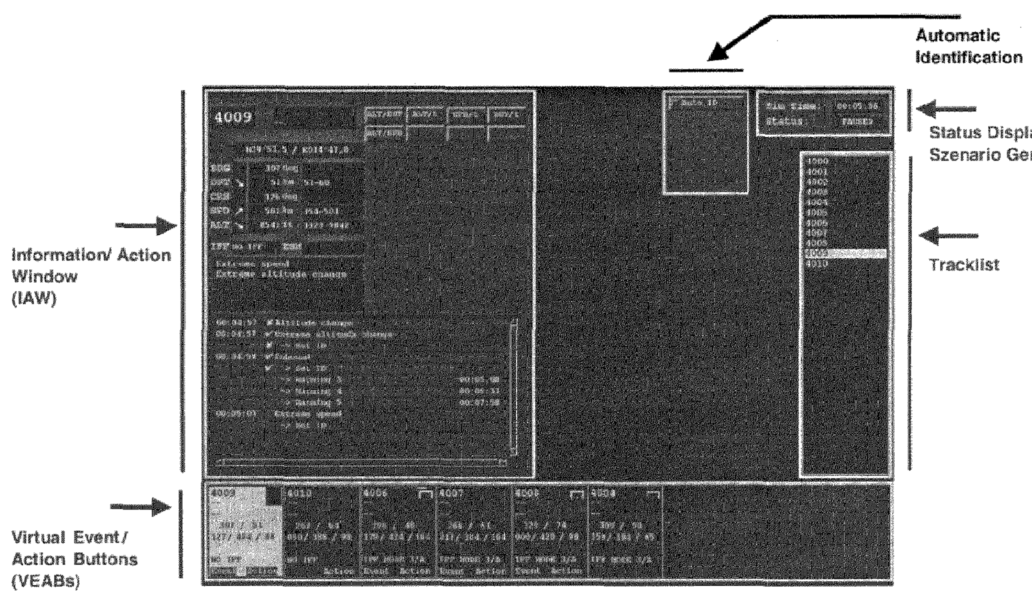

Figure 6: Graphical interactive user interface for ID/REC

the kinematic track data during the observation period, histories of speed, altitude, and distance as well as relations of altitude versus distance or speed. Besides these quantitative information additional qualitative information is presented textually. The sum of this information serves as an exhaustive operator support in situation/problem awareness.

Additional support for situation perception and assessment as well as for decision making and task performance is given by the presentation of task relevant events and related actions in an event/action list. This list contains events occurred combined with relevant action proposals in a chronological order. Selecting a special event from the list will show additional information characterizing and explaining that event. Selecting a proposed action from the list will show additional information related to the causing event as well as a decision or action suggestion with explanation for that special suggestion. These decision/action suggestions together with the presentation of alternatives support the solution generation of human operators.

In action execution the human operator is supported in the way that he is able to directly confirm the system's suggestion, choose and execute an proposed decision/action alternative or delete the decision/action suggestion. Additionally, the execution of actions consisting of an activity sequence is supported by the presentation of a time-line of the activities to be performed as well as of specific alerts to perform these activities optimally in time and distance or space.

Besides the situation-relevant information presented automatically by the support system there is the possibility to present additional preprocessed information on operator demand. This are histories of the kinematic data altitude, distance, and speed as well as relations between these values.

For operator relief there is the possibility on operator demand to automatically identify tracks fulfilling predefined criteria like, e.g., flying en route an air lane and emitting a civil IFF code.

5 Summary and Conclusion

Difficulties of human operators performing demanding problem solving tasks in natural settings have given rise to the need for support systems that can assist them in assessing and reacting to complex and rapidly changing situations. Obviously, problem solving tasks in such situations, especially military situations, may be supported by knowledge-based systems. At present it may not yet be possible to design a system addressing all possible events in highly ambiguous situations, such as those found, for instance, in military crisis reaction operations or operations other than war. But it is already possible to develop support systems that complement human's ability in perceiving such situations and in responding appropriately in novel situations. The concepts presented in this paper provide a systematic approach for the design of knowledge-based systems to support problem solving in complex situations. The basis of the approach is a generic description and framework of the human problem solving process itself.

The knowledge-based user assistant system developed and implemented for supporting decision making and action taking in naval air defense situations demonstrates the potential of such an approach. With the developed interface demonstrator, the advantages of this concept for operator support in complex problem situations like identification/recognition (ID/REC) could be shown.

The information presentation provides the decision makers with needed information, thus supporting all three levels of SA: perception, comprehension, and projection in the tactical and operational area. The information is displayed corresponding to the task-relevant operator needs, i.e., he can easily perceive and use the information without undue cognitive effort. Thus, operator workload is reduced because the information corresponds directly to his task goal, i.e., for identification of air targets to encounter possible threats in air defense.

In addition to SA support through prompts and warnings operators are alerted to task-relevant events and prompted to the appropriate actions by specific proposals and by guidance for action sequences. In addition to situation awareness, this improves decision making and action command. However, the ultimate decision remains with the human operator himself, thus, keeping him as an integral and critical part in the decision loop.

The knowledge-based user interface concept developed is a very general one and can be applied to different kinds of operator support systems for a variety of different missions and tasks. Human operators will be supported by information presentation and user guidance which are adapted to mission, situation, task, system status, as well as to operator abilities. For the development of the demonstrator an object-oriented approach and a modular architecture have been applied that allow changes and extensions of the demonstrator to be made easily. Therefore new as well as additional functions can be integrated quickly.

The concept of the knowledge-based user interface consisting of a knowledge-based user assistant (KBUA) and a multi-media user interface will be further developed. It is actually adopted for developing a support system to aid the CIC team in developing and using doctrines for automatically controlling the combat direction system of a German Navy frigate.

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